

# Beauty Production in Deep Inelastic Scattering at HERA using Decays into Electrons

R. Shehzadi (for the ZEUS Collaboration)

*Physikalisches Institut, Universität Bonn, Germany*

**Abstract.** The results from a recent analysis on beauty production in deep inelastic scattering at HERA using decays into electrons from the ZEUS collaboration are presented. The fractions of events containing  $b$  quarks were extracted from a likelihood fit using variables sensitive to electron identification as well as to semileptonic decays. Total and differential cross sections were measured and compared with next-to-leading-order QCD calculations. The beauty contribution to the proton structure function  $F_2$  was extracted from the double-differential cross sections.

**Keywords:** HERA, Beauty, Deep Inelastic Scattering

## INTRODUCTION

The measurement of beauty production in  $ep$  collisions at HERA provides a powerful tool for testing the proton structure and perturbative Quantum Chromodynamics (pQCD). The dominant production process is boson-gluon fusion between the incoming virtual photon and a gluon in the proton. When the negative squared four momentum of virtual photon,  $Q^2$ , is large compared to the proton mass, the interaction is referred to as deep inelastic scattering (DIS). Different kinematic variables which are used to describe  $ep$  interactions at HERA are:  $Q^2$ , the Bjorken scaling variable,  $x$ , and the inelasticity,  $y$ .

In this analysis [1], beauty production in DIS was studied using the semileptonic decays to electrons. The measurements are compared to a leading order plus parton shower Monte Carlo (RAPGAP) [2] as well as QCD predictions at next-to-leading order (NLO), calculated using HVQDIS program [3]. This program is based on the fixed-flavour-number scheme (FFNS), in which heavy flavours are generated dynamically in the hard subprocess.

## DATA SELECTION

The analysis was performed with data taken by the ZEUS detector from 2004 to 2007, when HERA collided electrons or positrons with energy  $E_e = 27.5$  GeV with protons of energy  $E_p = 920$  GeV. The corresponding integrated luminosity is  $363 \text{ pb}^{-1}$  at centre-of-mass energy  $\sqrt{s} = 318$  GeV. Standard cuts [4] were applied to select DIS events in the range  $Q^2 > 10 \text{ GeV}^2$  and  $0.05 < y < 0.7$ . Electron candidates from semileptonic decays of  $b$  quarks were selected from Energy Flow Objects (EFOs) having a transverse momentum  $0.9 < p_T^e < 8 \text{ GeV}$  in the pseudorapidity range  $|\eta^e| < 1.5$ . Electrons from identified photon conversions were rejected. The electron candidate was required to be associated to a jet with  $|\eta^{\text{jet}}| < 2.0$  and  $p_T^{\text{jet}} > 2.5 \text{ GeV}$ .

## SIGNAL EXTRACTION

For the identification of electrons from semileptonic  $b$  decays, variables sensitive to electron identification as well as to semileptonic decays were used. Electron identification uses the measurement of the specific energy loss,  $dE/dx$ , in the central tracking detector, the ratio of the energy deposited in the calorimeter to the track momentum and the penetrating depth of the energy deposited in the calorimeter.

Semileptonic decays were separated from background using  $p_T^{\text{rel}}$ , the relative transverse momentum component of the electron candidate relative to the direction of jet axis;  $\Delta\phi$ , the difference of the azimuthal angle between the electron direction and the missing transverse momentum vector; and  $d/\delta d$ , the significance of the reconstructed decay length, where  $d$  is defined as the distance in  $X$ - $Y$  between the secondary vertex and the interaction point, projected onto the jet axis. The six variables were combined into one discriminating test-function variable using a likelihood hypothesis. For a given hypothesis of particle,  $i$ , and source  $j$ , the likelihood,  $\mathcal{L}_{ij}$ , is given by

$$\mathcal{L}_{ij} = \prod_l \mathcal{P}_{ij}(d_l),$$

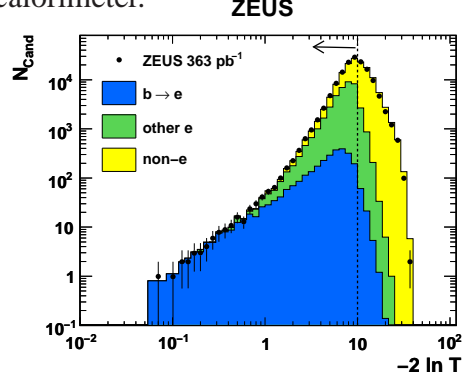
where  $\mathcal{P}_{ij}(d_l)$  is the probability to observe particle  $i$  from source  $j$  with value  $d_l$  of a discriminating variable. The particle hypotheses  $i \in \{e, \pi, K, p\}$  and the sources,  $j$ , for electrons from semileptonic  $b$  decays, electrons from other sources including semileptonic  $c$  decays and fake electrons were considered. The test function  $T_{ij}$  was defined as

$$T_{ij} = \frac{\alpha_i \alpha'_j \mathcal{L}_{ij}}{\sum_{k,l} \alpha_k \alpha'_l \mathcal{L}_{kl}}$$

The  $\alpha_i, \alpha'_j$  denote the prior probabilities taken from Monte Carlo. The distribution of likelihood test function is shown in Figure 1. The distribution is fit using the expected distributions for beauty, other electrons and fake electrons to determine the fractions of events from each source. The fit range of the test function was restricted to  $-2 \ln T < 10$ . The fit provides a very good description of data. Figure 2 shows signal-enriched distributions ( $-2 \ln T < 1.5$ ) for the variables in the likelihood-ratio test function, which are sensitive to the different origins of the electron candidates. All distributions are reasonably well described.

## SYSTEMATIC UNCERTAINTIES

The systematic uncertainties were calculated by varying the analysis procedure and then repeating the fit to the likelihood distributions [4]. Different sources of systematic uncer-



**FIGURE 1.** The distribution of  $-2 \ln T$ , where  $T$  is the test function, using the beauty hypothesis for electron candidates.

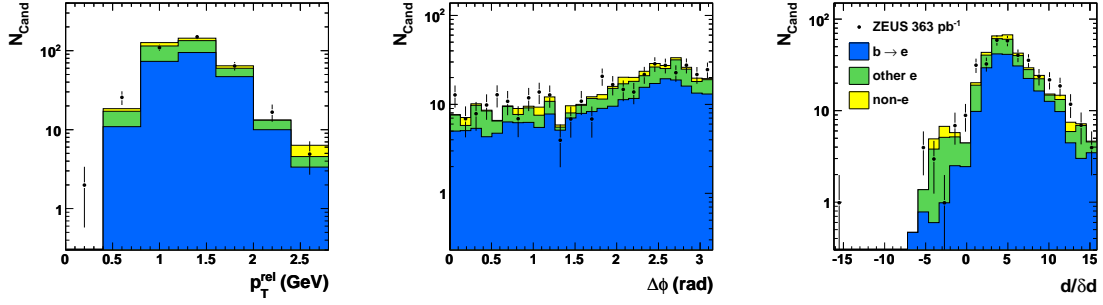


FIGURE 2. Distributions of  $p_T^{\text{rel}}$ ,  $\Delta\phi$  and  $d/\delta d$  for the signal-enriched region ( $-2\ln T < 1.5$ ).

tainty include variation of the DIS selection, likelihood variables, different background sources, jet energy scale, energy scales in the calorimeters and trigger correction. No single dominant contribution was observed and the quadratic sum of the systematic uncertainties was found to be of the same order as the statistical uncertainty.

## RESULTS

The total visible cross section and differential cross sections for  $b$ -quark production and the subsequent semileptonic decay to an electron with  $p_T^e > 0.9 \text{ GeV}$  in the range  $|\eta^e| < 1.5$  in DIS events with  $Q^2 > 10 \text{ GeV}^2$  and  $0.05 < y < 0.7$  were measured. Figure 3 shows differential cross sections as a function of  $p_T^e$  and  $\eta^e$  compared to the NLO QCD prediction and the RAPGAP MC scaled to the data. Both the descriptions from the NLO QCD calculation as well as the scaled RAPGAP cross sections describe the data well.

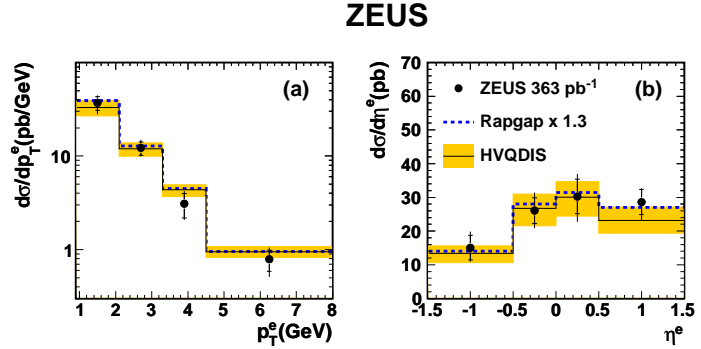


FIGURE 3. Differential cross sections for electrons from  $b$ -quark decays as a function of (a)  $p_T^e$  and (b)  $\eta^e$ .

## EXTRACTION OF $F_2^{b\bar{b}}$

The beauty contribution to the proton structure function  $F_2$  can be defined in terms of the inclusive double differential cross section as a function of  $x$  and  $Q^2$ ,

$$\frac{d^2\sigma^{b\bar{b}}}{dx dQ^2} = \frac{2\pi\alpha^2}{xQ^4} \left( [1 + (1-y)^2] F_2^{b\bar{b}}(x, Q^2) - y^2 F_L^{b\bar{b}}(x, Q^2) \right),$$

where  $F_L^{b\bar{b}}$  is the beauty contribution to the structure function  $F_L$ .

The electron cross section,  $\sigma_{b \rightarrow e}$ , measured in bins of  $x$  and  $Q^2$ , was used to extract  $F_2^{b\bar{b}}$  at a reference point in the  $x$ - $Q^2$  plane using

$$F_2^{b\bar{b}}(x_i, Q_i^2) = \frac{d^2\sigma_{b \rightarrow e}}{dx dQ^2} \cdot \frac{F_2^{b\bar{b}, \text{NLO}}(x_i, Q_i^2)}{d^2\sigma_{b \rightarrow e}^{\text{NLO}}/dx dQ^2}$$

where  $F_2^{b\bar{b}, \text{NLO}}$  and  $d^2\sigma_{b \rightarrow e}^{\text{NLO}}/dx dQ^2$  were calculated using the HVQDIS program. Figure 4 shows  $F_2^{b\bar{b}}$  as a function of  $Q^2$  for fixed values of  $x$ . The results from this measurement have been compared with the previous measurements from the H1 and ZEUS collaborations. The different measurements are consistent with each other. Also the results are compared to several NLO and NNLO QCD predictions [5]. The data are reasonably well described by the different theory predictions.

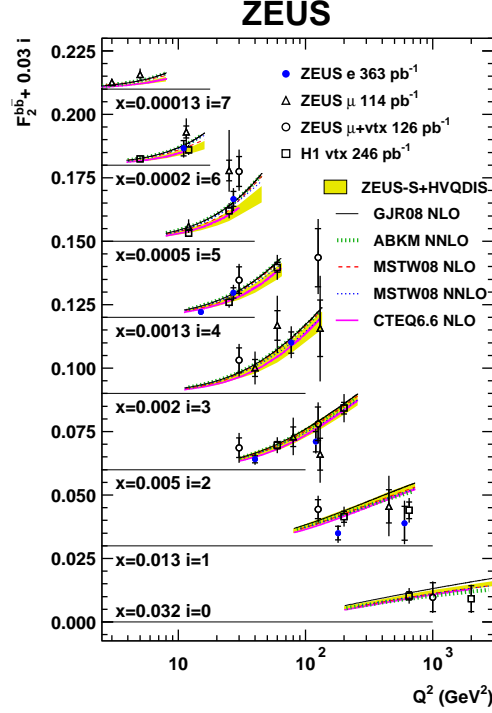


FIGURE 4.  $F_2^{b\bar{b}}$  as a function of  $Q^2$  for fixed  $x$  values.

## SUMMARY

A recent measurement of beauty production in DIS at HERA using decays into electrons was presented. A likelihood-ratio test function was used to identify the signal. The measured visible and differential cross sections are in agreement with the NLO QCD calculations.  $F_2^{b\bar{b}}$  was extracted from the double differential cross sections as a function of  $x$  and  $Q^2$ , and is in agreement with previous H1 and ZEUS measurements. For  $Q^2 > 10 \text{ GeV}^2$ , this measurement represents the most precise determination of  $F_2^{b\bar{b}}$  by the ZEUS collaboration. The results were also compared to several NLO and NNLO QCD calculations, which provide a good description of the data.

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